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# APPLICATION

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TITLE: EROSION MITIGATION FOR COLLECTOR OPTICS USING ELECTRIC AND MAGNETIC FIELDS

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# EROSION MITIGATION FOR COLLECTOR OPTICS USING ELECTRIC AND MAGNETIC FIELDS

## BACKGROUND

**[0001]** Lithography is used in the fabrication of semiconductor devices. In lithography, a light sensitive material, called a "photoresist", coats a wafer substrate, such as silicon. The photoresist may be exposed to light reflected from a mask to reproduce an image of the mask. When the wafer and mask are illuminated, the photoresist undergoes chemical reactions and is then developed to produce a replicated pattern of the mask on the wafer.

**[0002]** Extreme Ultraviolet (EUV) lithography is a promising future lithography technique. EUV light may be produced using a small, hot plasma that will efficiently radiate at a desired wavelength, e.g., in a range of approximately 11 nm to 15 nm. The plasma may be created in a vacuum chamber, typically by driving a pulsed electrical discharge through the target material or by focusing a pulsed laser beam onto the target material. The light produced by the plasma is then collected by nearby mirrors and sent downstream to the rest of the lithography tool.

**[0003]** The hot plasma tends to erode materials nearby, e.g., the electrodes in electric-discharge sources. The

eroded material may coat the collector optics, resulting in a loss of reflectivity and reducing the amount of light available for lithography.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0004]** Figure 1 is a block diagram of a lithography system.

**[0005]** Figure 2 is a sectional view of a light source chamber.

**[0006]** Figure 3 is a sectional view of a light source chamber including a magnetic field generator in a Discharge Produced Plasma (DPP) system.

**[0007]** Figure 4A is a side view of a magnetic field generator for collector optics.

**[0008]** Figure 4B illustrates the effect of a magnetic field on debris particles.

**[0009]** Figure 5 is a sectional view of a light source chamber including a magnetic field generator in a Laser Produced Plasma (LPP) system.

**[0010]** Figure 6A is a perspective view of nested collector optics and illustrates the effect of a generated magnetic field on a debris particle.

[0011] Figure 6B is an end view of the nested collector optics and magnetic field of Figure 6A.

[0012] Figure 7A is a perspective view of nested collector optics with a magnetic field generator according to another embodiment.

[0013] Figure 7B illustrates a dipole field generated by a wire in the nested collector optics of Figure 7B.

[0014] Figure 8 is a sectional view of nested collector optics with a magnetic field generator according to another embodiment.

[0015] Figure 9 is a perspective view of a light source chamber including collector optics and a foil trap to trap debris.

## DETAILED DESCRIPTION

[0016] Figure 1 shows a lithography system 100. A wafer, coated with a light sensitive coating ("photoresist"), and a mask may be placed in a lithography chamber 105. The pressure in the lithography chamber 105 may be reduced to a near vacuum environment by vacuum pumps 110. A light source chamber 115, which houses a light source, is connected to the lithography chamber 105. The pressure in the light source chamber may also be reduced to a near vacuum environment by the vacuum pumps 110. The

light source chamber and lithography chamber may be separated by a valve 120 which may be used to isolate the chambers. This allows for different environments within the different chambers.

**[0017]** The light source chamber 115 may be an EUV chamber, which houses an EUV light source. A power supply 125 is connected to the EUV chamber to supply energy for creating an EUV photon emitting plasma, which provides EUV light for lithography. The EUV light may have a wavelength in a range of 11 nm to 15 nm, e.g., 13.5 nm. The source may be a plasma light source, e.g., a laser plasma source or a pinch plasma source. Plasma-producing components, such as electrodes, in the EUV source may excite a gas, such as Xenon, to produce EUV radiation. The EUV chamber may be evacuated by the vacuum pumps 110.

**[0018]** Figure 2 shows a sectional view of an exemplary EUV chamber. The light source, in this case a discharge produced plasma (DPP) source 205, and collector mirrors 210 for collecting and directing the EUV light 215 for use in the lithography chamber 105 are inside the EUV chamber. The collector mirrors 210 may have a nominally conical/cylindrical structure.

**[0019]** Tungsten (W) or other refractory metals or alloys that are resistant to plasma erosion may be used for

components in the EUV source. However, plasma-erosion may still occur, and the debris produced by the erosion may be deposited on the collector mirrors 210. Debris may be produced from other sources, e.g., the walls of the chamber. Debris particles may coat the collector mirrors, resulting in a loss of reflectivity. Fast atoms produced by the electric discharge (e.g., Xe, Li, Sn, or In) may sputter away part of the collector mirror surfaces, further reducing reflectivity.

**[0020]** In an embodiment, a magnetic field is created around the collector mirrors to deflect charged particles and/or highly energetic ions 220 and thereby reduce erosion. A magnetic field may be generated using a solenoid structure. This magnetic field may be used to generate Lorentz force when there is a charged particle traveling perpendicular or at certain other angles with respect to the magnetic field direction. By applying high current (I) and many loops around the ferromagnetic tube, a high magnetic field can be generated.

**[0021]** Figure 3 shows an exemplary arrangement including a magnetic field generator 405 added in the collector optics. Figure 4A is enlarged view of a single collector element with the magnetic field generator. The magnetic field generator includes a ferromagnetic core 510 and a

coil 520 with many loops to improve the field strength. High velocity particles or ions 530 may be deflected away from the surface of the collector optics by the magnetic field 540 as shown in Figure 4B, thereby reducing any sputtering or erosion of the surface material. A cooling system may be included around to the solenoid structure for thermal management.

**[0022]** In an alternative embodiment, a magnetic field generator 570 may be implemented in a laser produced plasma (LPP) system.

**[0023]** The collector optics may have a nested shell arrangement, as shown in Figures 6A and 6B. The collector optics may include an inner shell 602, and outer shell 604, with one or more intervening shells 606. Each of the shells may have a reflective inner surface (i.e., facing toward the center of the shell structure) and a non-reflective backside.

**[0024]** An azimuthal magnetic field 608 may be produced by passing a current down the length of the inner and outer shells 602, 604, or alternatively, separate extra-thick shells concentric with the actual reflective shells. Such a field would then act to carry a positively charged ion 610 towards the non-reflective backside of each collector shell.

[0025] In an exemplary system, inner and outer current-carrying shells (coaxial with the reflective shells) of 1cm thick copper are provided. In an embodiment, the outer shell has a radius of 10cm and a cross-sectional area (2 pi r dr) of approximately 6000cm$^2$, and a length of 20cm. The amount of current such a shell can tolerate is given by:

[0026] R = ? L/A = $2\cdot10^{-8}$ * 0.2m / $6\cdot10^{-3}$ m$^2$ ~ $6.6\cdot10^{-3}$ ? .

[0027] Current: I = sqrt(P/R)= sqrt(1kW/$6.6\cdot10^{-3}$ ? ) = 39kA.

[0028] This assumes that the shell can tolerate a heat load of 1kW over the shell. This is only a small fraction of heat delivered by a high volume manufacturing (HVM) source (100s of kW) and corresponds to a heat loading of only 1kW/(2 pi * 10cm*20cm) ~ 1 W/cm$^2$.

[0029] Using Ampere's law, the strength of the magnetic field produced using this current is given by:

[0030] B ~ $?_0$I/4?r = $1.26\cdot10^{-6}$ ?/m * $3.9\cdot10^4$ A / (4?*0.1m) = 0.04 T

[0031] Assuming a radius of 1m is required to match the curvature of the shell, the magnetic field could deflect a single-charge Xe ion with a speed given by:

[0032] R = mV / qB -> V = qBR/m = $1.6\cdot10^{-19}$ C * 0.04 T * 1m / $2\cdot10^{-25}$ kg = $3.2\cdot10^4$ m/s

**[0033]** In eV: KE = $0.5 * 2 \cdot 10^{-25}$ kg * $(3.2 \cdot 10^4$ m/s$)^2$ * $6.3 \cdot 10^{18}$ eV/J = **640 eV**

**[0034]** Such energies may cover the vast majority of ions discharged from typical EUV sources. The small minority with energies of several keV might be slowed to 500eV or less by the time they reach the collector section by introducing a buffer gas.

**[0035]** In an embodiment, a series of insulated wires 702 are wrapped around the outside of each shell, thus avoiding any blockage of the light, as shown in Figure 7A. The wires 702 may be charged to a potential while the shells are held to a ground 704. Near one of the wires, the presence of the grounded plane results in a dipole field 710, as shown in Figure 7B. The strong gradients present in the dipole field may serve to collect even neutrally charged particles.

**[0036]** For an embodiment with a wire wrap pitch of 2mm and wire size of 200micron held at 200V, a rough estimate of capture time for a 100nm $SiO_2$ particle (density 2300 kg/m$^3$ ($m_p = 1.2 \cdot 10^{-18}$ kg)) with a charge of 5eV is 0.1 ms, and 0.1s for the same particle with no charge.

**[0037]** The embodiments described above utilize magnetic fields to mitigate debris. In alternative embodiments, electric fields may be used to mitigate debris. For

example, in an embodiment, each collector shell may be split into two conducting layers, which are separated by an insulator 802, as shown in Figure 8. The reflective layer 804 is charged to a positive state and the non-reflective side 806 to a negative state. This creates an electric field 808 pointing away from each reflective surface 804, and towards the backing of the neighboring shell. This approach may work particularly well for positively charged ions, carrying them away from the reflective surfaces and towards the non-reflective surfaces. Positively charged ions are known to be one of the primary sources of damage of the collectors. However, this may not work as well for neutrals as the field gradient would be relatively weak.

**[0038]** For an embodiment with 10 cm long plates separated by 1cm and a potential difference of 100V, rough estimates suggest singly charged (1 eV) Xe atoms with energy up to 2.5keV could be captured.

**[0039]** In other embodiments, the wire and split-plate approaches described above in connection with Figures 7A and 8, respectively, may be combined in various ways. For example, a split-plate approach may be used for a section of the collector nearest the light source and wires may be applied to a section farthest from the light source. Alternatively, wires or bumps may be placed on the non-

reflective collector side to introduce larger field gradients and thus increase the capture rate neutrals. In another embodiment, electret fibers may be used instead of wires connected to a power supply. Electret fibers are permanently imbued with an electric dipole moment. Electret fibers are commercially available, and are produced by the mature process of polymer melt-blowing with either corona charging or electrostatic fiber spinning. In the latter technique, the fibers are continuously released in liquid state out of a die into a region of a strong electric field. After some distance the fiber crystallizes with the electric field embedded in it. Fiber thickness can reach below 1 micron, although 100 microns is used in the present description for mechanical reliability. In another embodiment, the backside surface of each collector may be grooved or textured to assist collecting any particles that are drawn to the surface. In yet another embodiment, either charged wires or electret fibers could be attached perpendicularly between the shells, forming a web that would attract particles. A disadvantage to this approach is that some light would be absorbed and fast particles may make it through the web. However, negatively charged particles would be attracted to the reflective

surface, making this approach favorable if such particles were in the minority.

**[0040]** In an embodiment, debris-contaminant "foil traps", e.g., foil elements 902, may be positioned between the source 205 and the collector mirrors 210, as shown in Figure 9. The foil elements may be small, thin foils spaced apart from each other by, e.g., 1mm and spaced apart from the source by, e.g., 10-20mm. Typically, the debris particles travel in a jagged path characteristic of Brownian motion. This path makes the debris particles susceptible to striking, and being captured by, the foil traps.

**[0041]** The outer and inner current-carrying shells may extend towards the foil trap and thus extend the magnetic field into the trap. The thinly spaced foils may capture ions only slightly deflected, giving the magnetic field more time to act on an ion.

**[0042]** In the embodiments above, the magnetic field may be enhanced by incorporating ferrous materials into the various components.

**[0043]** A number of embodiments have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit

and scope of the invention. Accordingly, other embodiments are within the scope of the following claims.